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THE EVOLUTION OF A FAMILY OF AIR DEFENSE MODELS (TACOS, A HISTORICAL REVIEW)

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This document presents a historical review of the family of the Tactical Air Defense Computer Operational Simulation (TACOS) models that have been used or are now being utilized within the Army's air defense community.

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SUMMARY

This report presents a historical review of the family of Tactical Air Defense Computer Operational Simulation (TACOS) models that have been used or are now being utilized within the Army's air defense community. The different versions of the TACOS model are discussed. The evolution of each version is described along with the new features and capabilities that distinguish one version from another. A brief summary of the TACOS II model is presented.

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THE EVOLUTION OF A FAMILY OF AIR DEFENSE MODELS
(TACOS, A HISTORICAL REVIEW)

1. INTRODUCTION

During the early 1960's and the Robert McNamara era of the Department of Defense (DOD), an increase in the importance of cost effectiveness, systems analysis, and trade-off type studies was seen in the DOD decision-making process. A "domino" effect of the "McNamara" logic was reflected throughout and within all Armed Services. In order to conduct those in-depth comparative studies and analyses, different tools and methodology were needed. This gave rise to many new computerized simulation models that could (1) be used to conduct appropriate studies and investigations and (2) help "sell the product" once it reached the DOD levels.

The US Army's air defense community was not immune to the need of improved study methodology and additional tools for analysis. The Air Defense Agency (ADA) located at Fort Bliss, Texas had the charter to conduct all user-oriented operational and tactical air defense studies. To meet the needs of some specific studies in 1962, a new series of computerized simulation models were written by the ADA and became known as the Computerized Air Defense Wargame (CADWAG) series. As the CADWAG series began to be used, it became apparent quickly that a more detailed modeling of the environment and air defense weapon systems was mandatory. This led to the Tactical Air Defense Computer Operational Simulation (TACOS) model. Likewise, the TACOS model has gone through constant revision and modification such that at the present time the Army has a wide assortment of different versions of TACOS available for use to conduct operationally oriented air defense studies.

2. PURPOSE

The purpose of this report is to present a compendium on all the versions/levels of the TACOS air defense model that have been used or are now in use within the Army's air defense community. No attempt will be made to include versions of TACOS that are being used by the US Air Force, contractors and other government agencies. How different versions of TACOS relate to each other, as well as the significant differences that distinguish one from the other will be shown.

Upon reviewing this compendium, the reader should be in a more enlightened position in appreciating and understanding the "family" of TACOS models. Hopefully, interested analysts can use this compendium as a guide in helping to select the appropriate model for use in air defense studies and investigations.

This compendium will not contain a detailed description of any version of TACOS. Detailed documentation does exist for what is considered to be the Army's base TACOS model. The documentation includes (1) an Executive Summary, (2) a Programmer Analyst Manual and (3) a User/Planner Manual.

3. TACOS MODELS

3.1 TACOS I. As indicated earlier the CADWAG series of models were developed by the ADA at Fort Bliss, Texas during the early 1960's. These were event-stepped, operationally oriented computerized models designed to assist in studying NIKE HERCULES, HAWK, Mauler and AADS-70. Three significant areas were lacking in the CADWAG series; namely, terrain, air-to-surface air defense suppression and the modeling of air defense gun systems. Due to the desire to improve upon these three deficiencies and the need for more detailed modeling of Field Army air defense weapon systems, improvements were made to the CADWAG series of models with one model evolving from that effort. This new model was coined the "Tactical Air Defense Computer Operational Simulation" (TACOS) model and called TACOS I. TACOS I was used to simulate NIKE HERCULES, Basic and Self-Propelled (SP) HAWK, Air Defense (AD) Guns, Infrared (IR) weapons and SAM-D. Included in TACOS I was a digitized terrain base and the modeling of air defense weapon suppression. This modeling effort was accomplished by the ADA through a contract with Braddock, Dunn and McDonald, Inc. (BDM), El Paso, Texas.

3.2 TACOS II. It was stated earlier that this compendium would not contain a detailed description of any version of the TACOS model. However, since the TACOS II family of models provides such a broad range of capabilities and complexity, it seems appropriate to present a short review of the TACOS II model.

The Tactical Air Defense Computer Operational Simulation (TACOS) II represents interactions which occur between a large deployment of air defense systems and a large attack of aerial penetrator vehicles in a conventional setting over a Field Army. Up to 255 fire units (distributed as desired over 15 system types) and up to 255 cells (distributed over 10 types) may be engaged in a highly realistic simulation of an air defense battle. Figure 1 illustrates how TACOS II utilizes all elements of a simulated battle to aid the analyst in solving air defense problems.

TACOS II simulates large-scale air penetration/air defense engagements by representing the operational activity of individual penetrators and elements of the defense as these interact with each other and the environment. The model in a sense does "battle bookkeeping" and assures that the activities of each battle element are self-consistent and are consistent with the activities of other battle elements. Individual penetrator ground tracks and speeds are preplanned along piecewise-linear segments. Terrain-following altitude profiles may be computed in the model using the ground-track and digitized terrain data; altitude profiles may also be preplanned. Individual air defense fire units are sited to generate

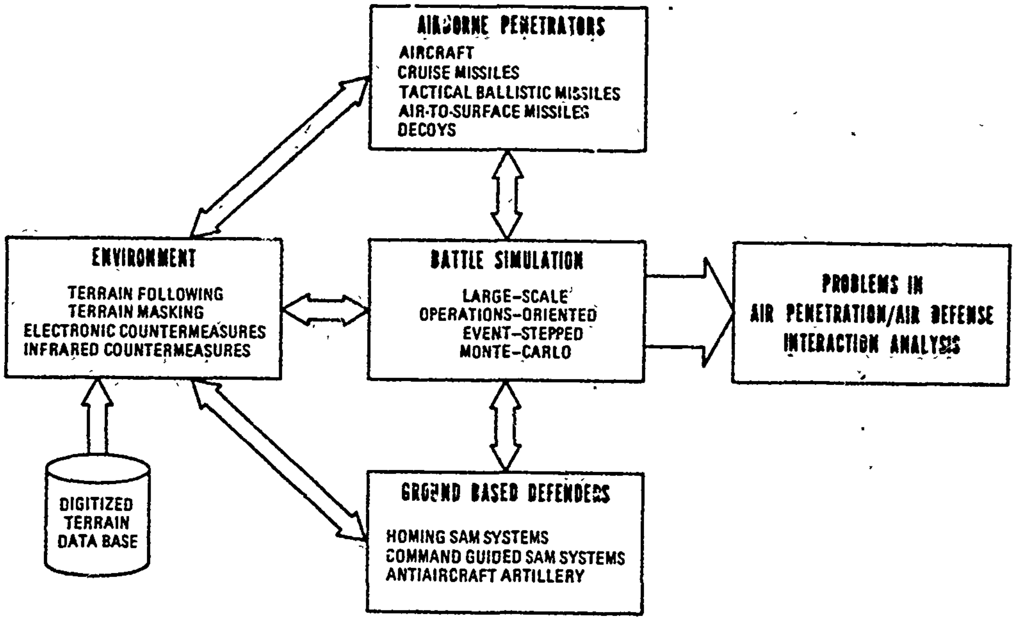

Figure 1 The TACOS II Simulation

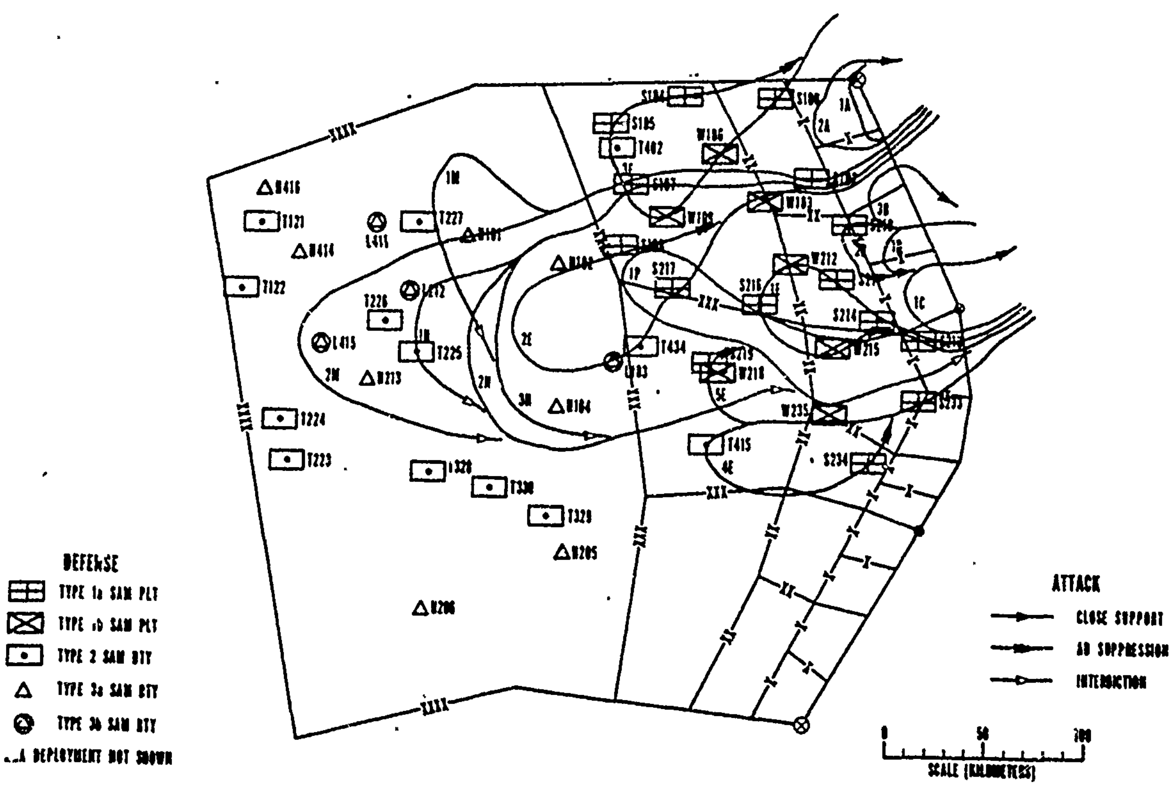

Figure 2 Typical Attack/Defense Situation

the air defense deployment. Each engagement conducted by each fire unit is explicitly simulated; critical events (e.g., acquisition, fire, intercepts, etc.) are recorded as they occur in the simulated battle. A battle map from a typical TACOS run is shown in Figure 2.

The TACOS II model utilizes an event simulation philosophy rather than a time step or frame method. Thus, relevant computations are made when it is necessary to schedule the occurrence of some event rather than repetitively computing and testing to determine whether that event has occurred. An event is an instantaneous change of state. In some cases, the change may be in the status of the relationship between a fire unit and a target or, in other cases, in the status of a fire unit. Some of the events explicitly simulated by TACOS are:

Penetrator sensor volume

Acquire/designate

Track

Fire

Enter terminal phase

Intercept

Assess

Re-evaluate

Limitation

Fire unit suppression attempt

Change priority

Penetrate fire volume

Launch ARM or decoy

Minimum ground clearance at intercept

Full reload

Burn-through

The TACOS II model evolved into a "modular" concept that is highly desirable in a large scale simulation like TACOS. The total simulation is composed of three major parts or Fragments (Frag's), each of which is one or more separate programs. The Frag's are described in the following paragraphs. Figure 3 shows a Functional Diagram of TACOS and Figure 4 depicts a Data Flow Diagram for the TACOS II model.

FRAG1 Description

FRAG1 simulates the air defense battlefield environment. This task is split into three parts. FRAG1A takes as input a digitized terrain file and a deployment of air defense sites to produce for each site a dominant mask function or DMF. A DMF describes the mask angle imposed by

A. MANIPULATE ENVIRONMENT
   1. DOMINANT MASK FUNCTIONS
   2. DETAILED FLIGHT PATHS
   3. GENERATE TERRAIN EVENTS
   4. GENERATE ECM EVENTS
   5. DETAILED SENSOR VOLUME PENETRATIONS
   6. SENSOR LIMITATIONS

B. PRESCHEDULE GEOMETRIC EVENTS
   1. SENSOR VOLUME PENETRATIONS
   2. SYSTEM LIMITATIONS
   3. FIRE VOLUME PENETRATIONS
   4. SUPPRESSION ATTEMPTS
   5. PENETRATOR PRIORITY CHANGES
   6. ARM AND DECOY LAUNCHES

C. INTEGRATE ENVIRONMENT EVENTS

D. TIME SORT EVENT FILE

E. SIMULATE AND REPORT RESULTS

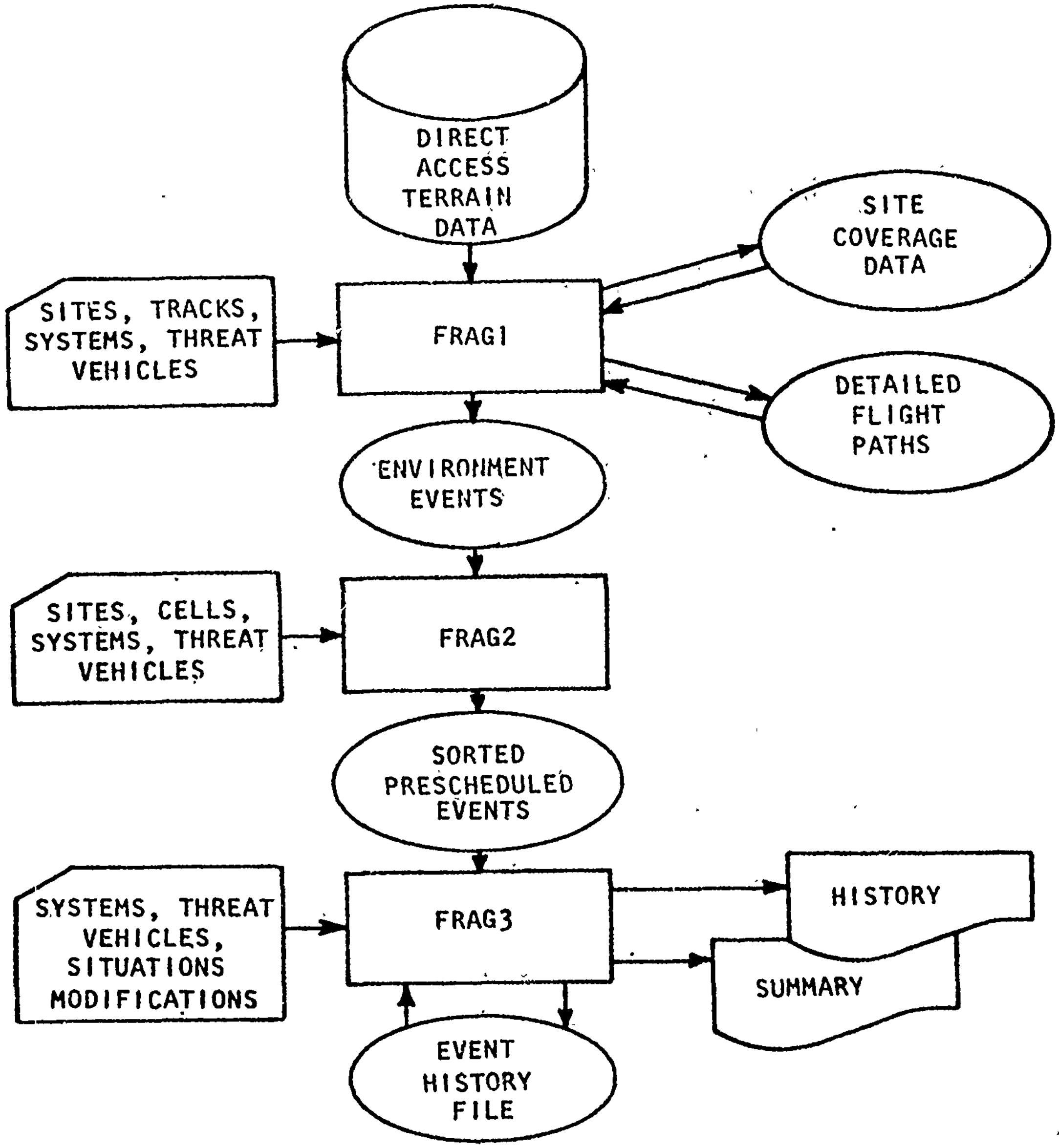

Figure 3 TACOS Functional Diagram

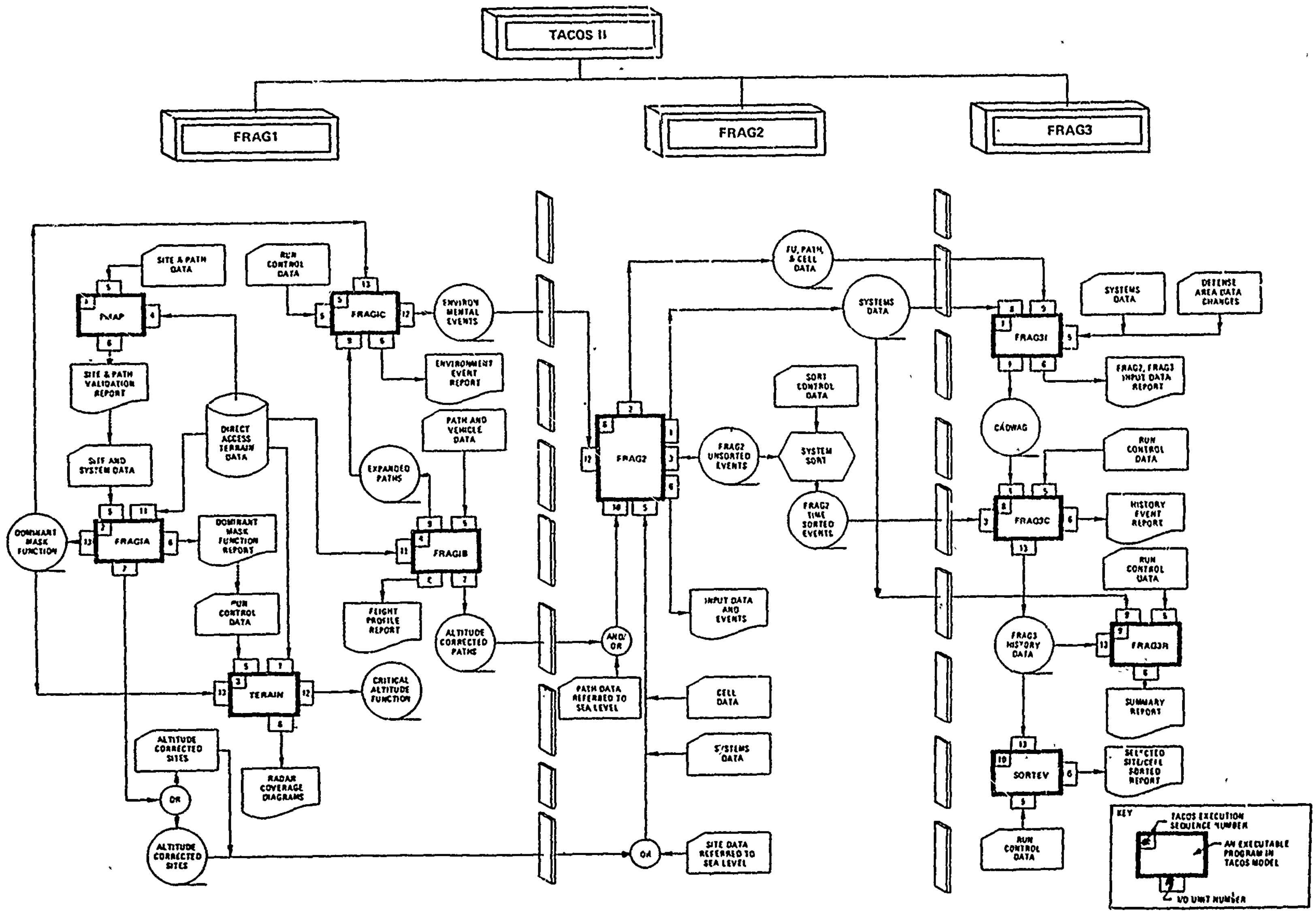

Figure 4 TACOS II Data Flow Diagram

terrain on the site under consideration as a function of azimuth and range. FRAG1B utilizes input piecewise-linear penetrator attack paths and the digitized terrain file to produce detailed flight path data which may include the use of a terrain avoidance or following flight algorithm. FRAG1C, in turn, inputs DMF's and detailed flight paths from earlier parts of FRAG1 along with a general description of the ECM environment to produce a file of environment events including terrain masking events, minimum ground clearance events, and burn-through events.

FRAG1A Function

The digitized terrain file used by both FRAG1A and FRAG1B is recorded on a direct access storage device for rapid random access and is comparable to a map case containing several map sheets. Each sheet in this file is a 100 kilometer square and is composed of some marginal data and about 40,400 elevation data points. The elevation information is represented by row after row of spot elevations read to the nearest 10 meters. These spot elevations are taken at 500 meter intervals in a row; rows are spaced 500 meters apart, forming a grid. The digitized terrain file is drawn upon to collect the piece of terrain appropriate to each site input to FRAG1A.

Once the required terrain has been obtained, FRAG1A proceeds to calculate the dominant mask function for the site. The algorithm implemented here is an analog of manual terrain profiling to determine intervisibility, with one major difference. Rather than simply determining a yes/no intervisibility judgment, the elevation angle to each visible ridgeline and the corresponding range are saved in a table marked off by azimuths. Site locations are specified in Universal Transverse Mercator (UTM) coordinates to eight digits (10 meter resolution). The altitude of the site may be input or computed by the program. The range of each system and system type (radar or optical) general information is also input to FRAG1A.

FRAG1B Function

FRAG1B expects attack course descriptions (paths) and penetrator terrain-following characteristics as input. These vehicle characteristics include a look-ahead range (which acts as a "smoothness" control on the path) and maximum and minimum maneuver limitations on the longitudinal plane of the vehicle. The attack course is specified as a piecewise-linear approximation to the ground track of the aircraft. Velocity is constant on a given segment of the track and may change discontinuously at a track turn point. Altitude is generally specified as desired ground clearances although it may be specified as desired absolute altitude. Terrain-following may be rejected to allow the vehicle to fly a piecewise-linear course between turn points in altitude. If terrain following is selected, the path control algorithm causes the vehicle motion to be approximated by arcs of circles with radii greater than those corresponding to the acceleration or g restrictions. The "aim

point" of a particular maneuver is to clear the highest (in look elevation angle) peak within a prespecified "look-ahead" range by the desired clearance elevation. Samples of the vehicle path are taken each time the ground position of the vehicle crosses a 500 meter grid line. These samples are stored on the detailed flight path data set and serve to facilitate the generation of minimum clearance, burn-through, and masking events by FRAG1C.

FRAG1C Function

This final section of FRAG1 merges data calculated in the two earlier sections with a specification of the ECM environment and system descriptions to produce minimum-ground-clearance events, terrain-masking events, and burn-through events. Each event includes a pair of times specifying the time of entry and time of exit from the indicated condition. Minimum-ground-clearance events are generated by determining all times of entry and exit of a path from the zone of input altitude above the ground. Terrain-masking events are generated by determining times when the elevation angle of a threat vehicle, as measured from the given site, falls below the elevation angle given in the DMF for that site as well as times when the site-vehicle elevation angle rises above the appropriate dominant mask. Burn-through or "ECM masking" events are generated by determining when the target range rises above the burn-through range and when the target range falls below the burn-through range. Other than DMF's and detailed flight paths, the inputs to FRAG1C include a list of sites for which environment events are desired, optional 100 point piecewise-linear near-in mask angle functions for any or all sites, minimum system sensor frequency bands and corresponding ECM vulnerability constants, standoff jammer deployment, operating bands and power densities, self-screening jammer operating bands and power densities, and threat vehicle radar cross-section as a function of off-boresight azimuth.

FRAG2 Description

The FRAG2 program module is the keystone of the TACOS, since this module calculates all events which are based on the geometry of threat-defense relationships and integrates these geometric events with environmental events calculated in FRAG1. This integrated event list then serves to drive FRAG3's dynamic engagement simulation module, CADWAG. An appreciation of the FRAG2 functional relationship to the TACOS model may be gained by examining Figure 3. FRAG2 uses a post-processor named FRAG2 SORT. Sequential execution of these two program modules converts raw air defense system characteristics, fire unit deployment data, threat attack data, and environmental events into a geometric and environmental event file for logical processing by FRAG3's dynamic war-game module, CADWAG.

FRAG2 preschedules events which may be determined from considering the geometry and timing of the relationship between penetrator paths and deployed sites. Events generated by FRAG2 are sensor volume penetrations, radial velocity, tracking sensor angular rate and launcher angular rate

limitations, fire volume penetrations, suppression attempts, threat priority changes, and ARM and decoy launches. Events generated by FRAG2 are integrated with environment events from FRAG1 and sorted into a sequenced file.

FRAG2 Function

Inputs to the event generation portion of FRAG2 include acquisition and tracking volume descriptions of IR or radar sensors, system pre-acquisition times, "vulnerable cylinder" radii for the suppression attempt model, missile flyout characteristics for the fire volume calculation, radial velocity, tracking sensor angular rate and launcher angular rate limitation threshold values, and threat geometric priority weights and transition ranges. Inputs relating to a specific battle situation include sites, paths, cells, and ARM or decoy launch points.

Processing in FRAG2 proceeds generally as follows. For each path/fire unit combination, all sensor volume penetrations are calculated. If the path is never unmasked while in any sensor volume or if the path never enters an acquisition volume, processing of this path/fire unit combination ceases and the next combination is examined. If the visibility criterion is met, then suppression attempts, limitations, fire volume penetrations, and priority transitions are calculated. Environment events are sorted as to relevance; those environmental limitations occurring outside of sensor volumes are discarded while relevant limitations are filed with other generated events.

Conceptually, the modeling for acquisition, path and fire volume penetrations, fire volume penetrations, and limitations of the varieties mentioned are relatively simple. The modeling underlying the fire unit suppression attempt calculation and the priority transition calculation is not obvious, however. First consider the fire unit suppression attempt model.

Suppression attempt events are simply notations that the ground range from the fire unit to the target projection has fallen below a critical value, one of the vulnerable radii. The two radii correspond roughly to "active" and "passive" fire unit conditions. These tags, in turn, may correspond to "radiating"/"nonradiating" or "recently active"/"inactive" dichotomies. Leaping ahead a bit in this discussion of FRAG's, the kill of fire unit is assessed in FRAG3 when the attacking threat vehicle reaches the crossing condition. At that point, the assumption is that appropriate bomb-type ordnance hits the fire unit and input ordnance P_k's take their toll.

The priority model in TACOS II is an extremely convenient and flexible tool for studying target choosing doctrines. In FRAG2, a geometric priority for a given target with respect to a given fire unit and its defended areas is calculated. The geometric priority varies as target position, velocity and aspect vary. In FRAG3, the geometric priorities of all targets in view of a given fire unit are immediately available any time that a re-evaluation cycle occurs. The effective

priority assigned to a given target in a re-evaluation cycle is simply the geometric priority of that target as assigned in FRAG2 modified by such factors as status of engagements with this fire unit, status of engagement with other fire units, and remaining ammunition supply.

FRAG3 Description

FRAG3 is composed of three parts or sections: FRAG3I, FRAG3C, and FRAG3R. The reading of input data from cards and the FRAG2 output file, and the sorting and storage of these data for use by FRAG3C is performed by FRAG3I. FRAG3C utilizes the FRAG2 event file to initiate and modify air defense engagements in the simulated battle. Engagement events are scheduled and outcomes are recorded to form the actual Monte Carlo game. FRAG3R is a postprocessor which utilizes FRAG3C history output to produce battle result reports and summaries.

FRAG3I Function

The FRAG3I program module prepares input data for FRAG3's dynamic engagement simulation module, CADWAG. An appreciation of the FRAG3I functional relationship to the TACOS model may be gained by examining Figures 3 and 4.

FRAG3C Function

FRAG3C is the section of the simulation which actually performs the engagement sequencing, Monte Carlo decisions, and history reporting. FRAG3C performs the simulation of the air defense engagements based on the geometric transitions and the environment transitions prescheduled by previous FRAG's.

An engagement in FRAG3C is initiated by either an unmask event, an acquisition volume penetration event, or by the threat re-evaluation following some engagement, given that these first two types of events had already occurred. Engagements in FRAG3C are terminated either normally, by the assessment of the outcome of an intercept, i.e., a kill or a non-kill, or abnormally, when the priority of another target sufficiently exceeds the priority of the target presently under engagement to force breaking the present engagement and beginning an engagement on the new target, or by some limitation occurring during the engagement of the present target.

FRAG3C simulates large-scale air penetration/air defense engagements by representing the operational activity of individual penetrators and elements of the defense as these interact with each other and the environment. The model, in a sense, does "battle bookkeeping" and assures that the activities of each battle element are self-consistent and are consistent with the activities of other battle elements.

Submodels in FRAG3C include a geometric priority scheme for determining engageability, command and control links, resource allocation, infrared and visual sensors, detailed radar volumes, intercept predictions, detailed

missile flyout, single-shot-kill probability, radial velocity and tracking rate limitations, electronic countermeasures and deceptive jamming, and comprehensive debug capabilities.

FRAG3R Function

FRAG3R is a postprocessor designed to summarize the results of a modeled battle simulated in FRAG3C. It utilizes the history data set to produce reports describing the effectiveness of the various air defense and threat vehicle systems described by the input to FRAG3C. There are at least 31 different types of reports which can be generated by FRAG3R. Production of the reports is controlled by logical variables which are input by the user.

TACOS II Ancillary Processors

TERAIN, PMAP, and SORTEV are not FRAGs of the TACOS II family. TERAIN and PMAP are preprocessors while SORTEV is a postprocessor. TERAIN considers only the sites as they exist on terrain. It has the capability to produce, based on line-of-sight considerations, radar coverage diagrams. These help the user to determine the optimum location for a site. PMAP considers both site and path locations. It produces reports and printed maps which show the ability of these entities to engage. Thus, the user is aided in making the most effective use of his available resources. After a simulation has run through FRAG3C, a question may arise about the operations of a particular site and/or path. SORTEV allows a printout of the history events of any sites/paths, alone or in combination. Thus, it may be seen that while TACOS II can be run without any of these peripheral processors, their use can significantly aid the user to complete a run and analysis in optimal time. Figure 4 depicts at what points during a TACOS run these ancillary processors are utilized to assist the analyst.

3.2.1 TACOS II.1. When TACOS I was used to conduct several air defense studies, other improvements became mandatory to further enhance the model. Based upon additional contractual support, TACOS I was modified and became known as TACOS II.1. TACOS II.1 included the following changes/enhancements to TACOS I:

1. Capacity to simulate larger tactical situations
2. More detailed modeling of SAM-D
3. Limited command and control logic
4. Terrain prediction logic for a system with such capability
5. Electronic countermeasures modeling

The ADA contracted BDM to implement these changes into TACOS I.

3.2.2 TACOS II.2. Very few changes were made to TACOS II.1 before it became known as TACOS II.2. These changes included IFF and IFF saturation. After attempting to use the new IFF logic in a study, it became clear that the logic was not detailed enough to properly play IFF and thus has not been used since.

3.2.3 TACOS II.3. Beginning January 1968, the US Army Missile Command conducted a DA-directed study entitled the "Technical Review of Army Air Defense Systems (TRAADS)." At that time TACOS II.2 was established locally at MICOM under contract with BDM. During the TRAADS effort it was determined that both IR weapons and gun systems needed some improved logic to properly address questions being investigated by the study. Modifications were made by BDM to TACOS II.2 which gave rise to TACOS II.3.

3.2.4 TACOS C^2. In late 1969, interest began to grow in studying the command and control (C^2) functions of Field Army Air Defense Systems. A review of all known air defense models in the country revealed the fact that no model existed which could be used to properly address the C^2 area. Following this search for existing models, the ADA at Fort Bliss, Texas decided to obtain contractual support to develop a model capable of addressing Field Army C^2 problems. This culminated in a contract with BDM, El Paso, Texas.

BDM's approach was to use the already existing TACOS II.3 as a base on which to build the new C^2 model. Thus, TACOS II.3 was expanded significantly to include an explicit treatment of command and control functions of the Army in the field. This revised model became known as TACOS C^2.

TACOS C^2 could simulate a variety of C^2 systems, doctrines, and a flexible communication network. Message origination, processing, scheduling and routing were simulated. TACOS C^2 is still a unique model and should be considered in a class separate from all other existing TACOS models mentioned in this report.

3.2.5 TACOS II.4. During the summer of 1970, a special DA study board was formed primarily to determine whether or not to recommend the entering of Engineering Development (ED) for SAM-D (Patriot). The study was entitled the Air Defense Evaluation Board (ADEB)—80, and the TACOS II.3 was the major analysis tool used to investigate the total Field Army air defense effectiveness. During the ADEB study, analysts from the ADA and MICOM expressed concern in some areas of the modeling of air defense missile systems. After the ADEB study MICOM obtained a contract to upgrade and improve TACOS II.3. The end results of that effort was TACOS II.4, which had the following improvements to TACOS II.3:

1. Expanded single-shot-kill probability (SSKP) Submodel. This new improved submodel allowed SSKP's to be input as a function of air defense system type and threat vehicle type and as a function of the following variables:

a. Target range

b. Target azimuth with respect to (wrt) the fire unit at launch or intercept

c. Target altitude

d. Aircraft stores, i.e., amount of ordnance onboard.

e. Benign or ECM environment

f. Incoming or outgoing wrt to fire unit

g. Number of live objects within a cell

2. Modeling of visual detection as a function of unmask range

3. Detailed modeling of stand-off, self-screening, or deceptive jammers and their effects on acquisition radars.

4. Detailed representation of acquisition ranges for radars using burn-through equations which included the following parameters:

   a. Antenna main lobe gain versus off-boresight angle

   b. Radar cross-section of targets versus pitch and azimuth angles

5. Expanded radar burn-through equations

The ADA at Fort Bliss utilized TACOS II.4 in a study and made a modification that allowed the SSKP's to be degraded due to target maneuvers. Different type maneuvers were input into the model via a specific "code" type and the SSKP reduced accordingly at intercept. The model remained to be called TACOS II.4.

3.2.6 TACOS II.5. All TACOS versions thru TACOS II.4 were written for execution on IBM 360 series digital computers. During mid calendar year (CY) 72, the ADA at Fort Bliss, Texas went forward to their Headquarters with a request for contractual support to convert the TACOS II.4 model from the IBM 360 computer over to other computing systems, i.e., CDC 6000 series, UNIVAC 1108, and others. Based upon a long series of events, it was decided at DA levels that MICOM would perform the task of converting TACOS II.4 from the IBM 360 system. It was decided to convert the model over to the CDC 6000 series only, with the converted model being made operational on the MICOM CDC 6600 computer and on a CDC 6500 computer located at Fort Leavenworth, Kansas.

It was the desire of all Army TACOS users for MICOM to incorporate into the model during this conversion several key changes made to TACOS II.4 by the ADA, BDM, MICOM and the US Air Force. It was agreed by all that the "newly" converted model would be established as the Army's base TACOS model and would be referred to as TACOS II.5. The following paragraphs present a short recap of all features that the presently operational TACOS II.5 has in addition to those of TACOS II.4. TACOS II.5 is still considered to be the base model.

3.2.6.1 Variable Terrain Granularity. Prior to this new feature, the digitized terrain base in TACOS was modeled with a horizontal rate of one terrain point each 500 meters. Thus, the "grid-size" was said to be 500 meters. Based upon this new feature, digitized terrain can be played at any granularity desired that is at least as large as 63.5 meters.

3.2.6.2 Pseudo-Track. This feature allows for an air defense weapon system to maintain detailed or close surveillance of targets which are not being actively engaged by the system. Once resources become available, i.e., an engagement channel becomes free, a target must be in "pseudo-track" before the engagement can continue in progress. This capability enables TACOS to simulate a system that can maintain a "track file" on a significant number of targets while not engaging them actively.

3.2.6.3 Special Fire Volumes. This capability allows the simulation of detailed fire/no-fire zones around a fire unit. Each fire volume is described by a series of altitudes and velocity-dependent two-dimensional bounded regions lying in parallel planes. The distance between the parallel planes is controlled by an altitude input parameter. When a weapon system has the capability for detailed intercept predictions, special fire volumes are used.

3.2.6.4 Fully Correlated Gunfire. TACOS II simulates the operation of antiaircraft guns in much the same fashion as it simulates the operation of homing surface-to-air missile systems. The prime differences lie in the portrayal of the gun projectile flyout and in the determination of the kill probability. In all versions of TACOS II thru TACOS II.4, the final kill probability (P_k) for a single burst was determined via an "uncorrelated" burst P_k equation. This equation inherently depicted each round within the burst to be independent from each other with respect to aiming error. A modification was made to TACOS II.4 whereby the gunfire submodel simulated the situation of "correlated" fire by a gun system. In this case all rounds within a burst were assumed correlated with respect to aiming error. This has been considered by most users of TACOS as a major improvement for air defense gun system methodology in the model.

3.2.6.5 IRCM Flare Drop. This modification allowed for the explicit simulation of attacking penetrators to drop IR flares at any desired drop rate as they enter/exit the defended air space. Given that a flare(s) was dropped by a hostile aircraft while an IR homing missile was in-flight against the aircraft, the possibility of missile capture by the flare(s) was simulated.

3.2.6.6 Variable Reduced Engagement Range. For each air defense weapon system type and penetrator type combination, a maximum of 16 reduced engagement ranges could be portrayed. These were input as a function of four separate target speeds and four different target altitudes. These reduced engagement ranges are known as "REDNGR" among TACOS users and are used to restrict the engagement of a target by a fire unit until the target is within the appropriate reduced engagement (REDNGR) range. Prior to this modification, only one REDNGR was input per system/target type combination.

3.2.7 TACOS II.5.1. A major modification was made by MICOM to TACOS II.5 in the fall of 1975 that now permits high energy laser systems to be played in the weapons mix. Due to unique features and capabilities of these systems, a significant number of new submodels were required. Included in this effort was the incorporation of methodology for determining the realistic flight path of an aircraft and its orientation with respect to a ground based air defense site. Using this methodology, the model now calculates the roll angle, pitch angle and yaw angle of the target. This gives a detailed "picture" of the target to the fire unit and can be used to help calculate kill probabilities more precisely.

This version of TACOS has been used by the Systems Analysis Office at MICOM for one study, and the Air Defense School (ADS) at Fort Bliss, Texas is planning on using it during a HELTADS COEA sometime in CY 76. Once this version of TACOS is fully understood by the ADS, TACOS II.5.1 may be designated TACOS II.5 and will then be the base model.

3.2.8 TACOS II.5/AI. The US Air Force has had several contracts with BDM within the past few years to add Air Interceptors (AI's) to their version of TACOS. This effort was finished during CY 75, with analysts at Eglin Air Force Base, Florida utilizing the AI version of TACOS in an air base defense study.

Army users of TACOS within the past few years have consistently been plagued with the criticism that "the model does not include the contribution and overall effects of Air Interceptors to the total air defense capability." To assist in rectifying this area, MICOM initiated an effort during late CY 75 to incorporate into the Army's TACOS II.5 model the appropriate AI logic contained in the Air Force's version of TACOS. This was completed in May 76.

This version of TACOS represents a major step forward in the evolution of the family of TACOS II models. The model can now simulate escort jamming, penetrator air superiority aircraft and other types of aircraft (ECM, escort, bombers, etc.) in a heterogeneous formation, Air Force Interceptor aircraft, air bases, ground controlled intercept (GCI) stations, command and control centers for the AI campaign, air-air "dogfights," and engagement zones for AI's and ground based air defense systems.

The BDM Corporation's Huntsville Office has published a valuable User's Manual on the TACOS II/AF-2 model for the US Air Force. The title of the report is, "TACOS II/AF-2, Users' Manual," Report Number BDM/E-72-49-F-0065. The report is very informative on the theory and methodology of the AI capabilities in the model.

3.2.9 TACOS II.6. During the summer of 1973, a special study task force was formed in Washington, DC to determine whether or not there was a requirement for an all-weather Short Range Air Defense System (SHORADS) for the Army in the field. The study title was the "SHORADS Requirement Study." One of the major operational effectiveness analysis tools used was TACOS II.4. To support the study effort BDM was awarded a contract

by the study group. Based upon questions being addressed by the study group, three significant modifications to TACOS II.4 were necessary and were implemented by BDM. The model variation incorporating these modifications, described briefly in the following paragraphs, became known as TACOS II.6.

3.2.9.1 Radar "Turn-Off"/"Turn-on" Tactic. This modification was made to allow an air defense weapon system with RF sensors to react to the situation in which it has been determined that an anti-radiation missile (ARM) has been launched and is guiding (homing) on the site. Based upon coded logic in the model and a set of input parameters, the site could decide to "turn-off" (shutdown) its radars for a specific time period before "turning-on" again. The turning-off technique had the effect of reducing the ARM's P_k to zero or to a reduced value which was determined by input and coded logic.

Sites could misidentify air-launched decoys as ARM's and improperly turn-off. If an air defense site has RF decoys deployed around it, the incoming ARM has a probability of impacting on the decoy instead of the true RF sensor.

3.2.9.2 Dynamic Route Selection. Prior to this modification, penetrator aircraft were "pre-programmed," in a fashion, against desired air defense sites. The situation could arise such that when the penetrator reached the point on its path to deliver ordnance on a site, the site could already be "dead," i.e., defeated by a penetrator earlier in the game. In this modification the penetrator logic was modified to incorporate a capability to respond to site condition (alive - dead) by choosing alternate routes for attacking "secondary" targets. As the penetrator proceeds down its track, designated decision points are reached. At each of these decision points, the penetrator is allowed the intelligence of knowing whether or not its primary target is alive. If alive, the penetrator proceeds to the primary target or to the next decision point. If the primary target is determined to be dead at a decision point, an alternate target is considered immediately. If an alternate target is chosen for attack, it now becomes a primary target and the series of primary/alternate target considerations begins all over again.

3.2.9.3 Close-in Mask Generation. This modification allowed for the effects of physical structures and foliage to be played on a site's visibility. These effects were lost during terrain data digitalization by the US Army Map Service. TACOS was modified to statistically generate close-in mask comparable in detail to close-in mask due to physical structures and foliage.

3.2.10 QR-TACOS. The Quick Response Tactical Air Defense Computer Operational Simulation (QR-TACOS) was developed to provide a major reduction in the amount of manual effort required for data input for the basic TACOS simulation. The QR-TACOS modification eliminated the majority of the tedium of deployment and attack path planning, and data collection for the two. The automated procedure eliminated the manual deployment

and attack planning. QR-TACOS has been put together in such a way that the real-world effects of terrain are accurately represented in the deployment and attack profile interaction. QR-TACOS replaces those elements of the overall TACOS model (FRAG1A, FRAG1B, FRAG1C) in which the defense units and threat are first input (see Figures 4 and 5). An area that QR-TACOS does not represent in detail is the effects of electronic countermeasures (ECM). QR-TACOS can simulate the effects of ECM to some degree by using degraded reaction times and radar sensor ranges.

QR-TACOS was developed and utilized during the SHORADS Requirement Study and has been used quite often since when very detailed deployments and raids were not required. Since QR-TACOS replaces FRAGs 1A, 1B, and 1C, TACOS II.1 - II.5 can be used along with it. Doing this, the analyst has the attractiveness of "fast turn-around" for data inputs for the FRAG 1A, FRAG 1B and FRAG 1C functions (this being accomplished through QR-TACOS) and the "fine-grain" features of FRAG 2 and FRAG 3.

3.2.11 TACOS II.7. Air defense concepts are being considered that have a sector-oriented radar which implies "sector coverage", not full coverage, i.e., less than 360^{o} coverage. The area of modeling these types of systems becomes complex when the system has the capability to turn its radar from one sector to another dynamically in an attempt to optimize air defense resources. A modification was made to TACOS II.6 during late CY 73 that now permits the simulation of an air defense system which has a dynamic radar sector reorientation capability.

The first task involved in incorporating this "trainability" submodel was exploring the general area of radar retraining to find the individual contributing elements. It soon became clear that two other features would be required besides the basic retraining submodel. These are a generalized function input capability and a separate missile launcher submodel. The generalized function input capability is required to give the model user all the flexibility needed to define which elements contribute (and by how much) to the retraining decision. The separate missile launcher submodel is required since the suitability of any new sector orientation depends on the number of missiles available for launch in that new sector. The model version resulting from these changes became known as TACOS II.7.

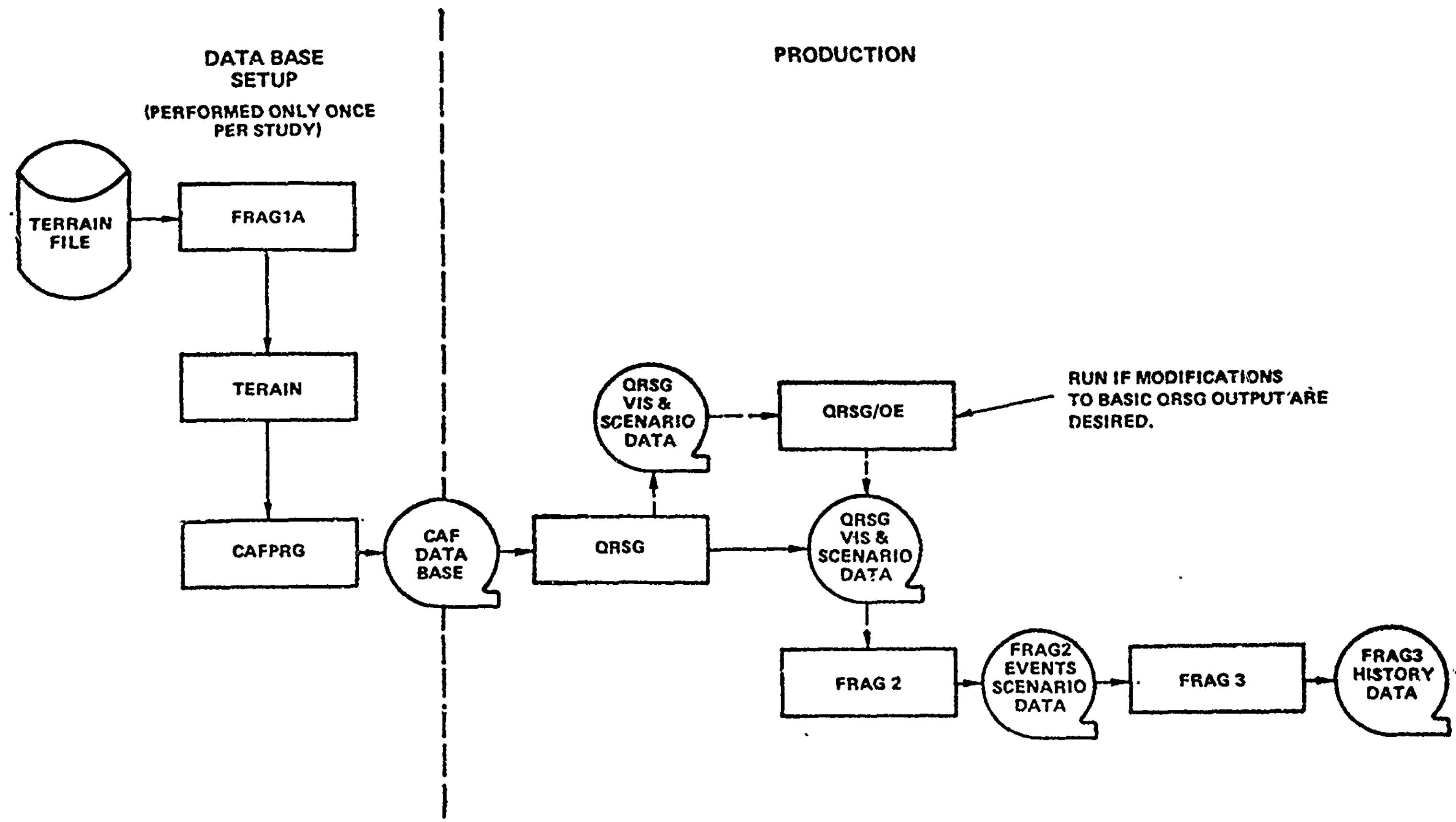

FIGURE 5 QR-TACOS PROGRAM RELATIONSHIP DIAGRAM

4. SUMMARY

Table 1 (page 20) provides data for a quick snap-shot overview of the significant features of each TACOS model. By comparing these features, one can quickly see the differences and the "evolution tree" associated with the TACOS family of models. This review of the evolution of the TACOS air defense model(s) does not include every effort exerted on the model; however, the key, significant, and most important ones from the Army's viewpoint have been mentioned.

The Army has developed a tremendous amount of TACOS in-house expertise within the past four years. Within MICOM, the "MICOM TACOS Resource Base" has been established employing programmer analysts, computer specialists and operations research analysts. Since the establishment of the Resource Base, no modification task has surfaced that could not be completed by MICOM. The Air Defense School (ADS) at Fort Bliss, Texas is continually, almost on a full-time basis, using the model. The ADS has made some major additions to FRAG3R and SORTEV that aid greatly the analysis of TACOS output data. The ADS's civilian work force, which is dedicated to TACOS, is growing; and additional improvements are expected on a continuous basis in the future. Due to this in-house expertise at MICOM and ADS, less and less reliance on the contractor has materialized. This can readily be seen by the small amount of contractual support used on the TACOS model since late CY 73.

TABLE 1. SELECTED SUBMODELS AND FEATURES OF THE ARMY'S FAMILY OF TACOS MODELS

SELECTED TACOS SUBMODEL/FEATURES	TACOS VERSIONS											
	I	II.1	II.2	II.3	II.4	II.5	II.6	II.7	II.5/ AI	C^2	QR-TACOS	II.5.1
TERRAIN												
Digitized Terrain	X	X	X	X	X	X	X	X	X	X	1/	X
Variable Granularity Terrain						X			X			X
RADAR SUBMODELS												
Detailed Range Equations				X	X	X	X	X	X	X		X
Geometric Volumes	X	X	X	X	X	X	X	X	X	X		X
Pseudo-Track						X	X	X	X			X
SSKP SUBMODELS												
2-Dimensional	X	X	X	X						X		
8-Dimensional					X	X	X	X	X			X
ELECTRONIC COUNTERMEASURES SUBMODEL												
Simple												
Stand-off Jamming	X	X	X	X								
Self-Screening	X	X	X	X								
Detailed												
Stand-off Jamming					X	X	X	X	X			X
Self-Screening Jamming					X	X	X	X	X			X
Deceptive Jamming					X	X	X	X	X			X
Escort Jamming									X			
GCI Strobing									X			
SPECIAL FIRE VOLUMES						X	X	X	X			X
FULLY CORRELATED GUNFIRE						X	X	X	X			X
IRCM FLARE DROP						X			X			X
VARIABLE REDNGR						X			X			X
AIR INTERCEPTORS									X			
HIGH ENERGY LASER SYSTEMS												X
RADAR TURN-OFF/TURN-ON							X					
DYNAMIC ROUTE SELECTION							X					
CLOSE-IN MASK GENERATION							X					
RADAR SECTOR REORIENTATION								X				
VISUAL DETECTION												
Not Function of Unmask Range	X	X	X	X								
Function of Unmask Range					X	X	X	X	X			X
COMPUTER ASSISTED DEPLOYMENT/ THREAT MODELING											X	

1/ Since the Quick-Response Scenario Generator of QR-TACOS replaces FRAG 1A, FRAG 1B, and FRAG 1C, QR-TACOS can be utilized with any TACOS version. However, some of the "fine-grain" modeling features of FRAG 1A, FRAG 1B, and FRAG 1C may be lost in doing so.

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